Land Prediction in NCEP Modeling Systems: 
*Current Status and Future Plans* 
*(NGGPS Land Team)*

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…and a large number of collaborators!
Outline

• Role of Land-Surface Models, Requirements

• Remotely-Sensed Products and Land Data Assimilation Status and Upgrades (support from NGGPS)

• Land Data Assimilation Systems at NCEP:
  - Global Land Data Assimilation System (GLDAS)
  - North American LDAS (NLDAS)

• Model Improvement, Testing & Validation

• Summary/Future

- Climate Forecast System (CFS)
  - GFS, MOM4, GLDAS/LIS/Noah, Sea Ice

- Regional Hurricane
  - GFDL, WRF-NMM + Noah
  - Waves: WaveWatch III
  - Ocean (RTOFS): HYCOM

- Regional NAM
  - NMAM
  - Noah land model
  - Short-Range Ensemble Forecast 21 members
    - WRF (ARW + NMM)
    - NMMB 7 members each
  - High Res Windows
    - WRF-ARW & NMMB

- Rapid Refresh
  - WRF ARW

- General Ensemble Forecast System (GEFS)
  - 21 GFS Members

- North American Ensemble Forecast System
  - GEFS, Canadian Global Model

- North American Land Surface Data Assimilation System
  - Noah Land Surface Model

- Ecosystem
  - EwE

- Regional Bays
  - Great Lakes (POM)
  - N Gulf of Mexico (FVCOM)
  - Columbia R. (SELF)
  - Chesapeake (ROMS)
  - Tampa (ROMS)
  - Delaware (ROMS)

- Dispersion
  - HYSPLIT

- Air Quality
  - CMAQ

- Space Weather
  - ENLIL

- Estuarine Forecasting System (ESTOFS)
  - ADCIRC
  - SURGE
  - SLOSH

- Waves
  - WaveWatch III

- Ocean (RTOFS)
  - HYCOM

- Rapid Refresh
  - WRF ARW

- RUC LSM
Role of Land-Surface Models & Requirements

• Land Surface Models (LSMs) provide surface flux boundary conditions for heat, moisture and momentum to the atmosphere for NCEP weather and seasonal climate models.

• Land models close surface energy and water budgets.

• Land Model Requirements:
  ✓ **Physics**: appropriate to represent land-surface processes (for relevant time/spatial scales) and assoc. LSM model parameters.
  ✓ **Atmospheric forcing** to drive LSM.
  ✓ **Land data sets**, e.g. land use/land cover (vegetation type), soil type, surface albedo, snow cover, surface roughness, etc.
  ✓ **Initial land states**: Compared to atmosphere, land states carry more memory (especially deep soil moisture), similar to the role of SSTs and ocean temperatures.
  ✓ **Land Data Assimilation**: some of these quantities may be assimilated, e.g. snow depth and cover, soil moisture.
  ✓ **Land Data Assimilation Systems (LDAS)**: provide initial land states for NCEP modeling systems.
**Land Model Physics: Flux Boundary Conditions**

\[
H = \rho c_p C_h U (T_{sfc} - T_{air}) \\
LE = LE_c + LE_t + LE_d
\]

- **Sensible heat flux** from soil surface/canopy
- **Latent heat flux** (Evapotranspiration)
- **Canopy Water Evaporation**
- **Transpiration**
- **Direct Soil Evaporation**
- **Emitted longwave**

**Surface fluxes balanced by net radiation (Rn),**
\[
R_n = H + LE + G
\]

- Rn = sum of incoming and outgoing solar and terrestrial radiation, with vegetation important for energy partition between H, LE, G, i.e. surface roughness & near-surface turbulence (H), plant & soil processes (LE), and heat transport thru soil/canopy (G), **affecting evolving boundary-layer, clouds/convection, and precipitation.**
Land Data Sets Used in NCEP Modeling Systems

**Vegetation Type** (1-km, IGBP-MODIS)

**Soil Type** (1-km, STATSGO-FAO)

**Max.-Snow Albedo** (1-deg, Robinson)

**Green Vegetation Fraction (GVF)** (monthly, 1/8-deg, NESDIS/AVHRR)

**Snow-Free Albedo** (seasonal, 1-deg, Matthews)

- Climatologies: fixed/annual, monthly, weekly.
- Near real-time observations, e.g. GVF “becoming” a land state.
NGGPS Project: Incorporate near-realtime Green Vegetation Fraction (GVF), validation with LST

• Climatology vs. near real-time GVF.

AVHRR 5-year “Climatology”

VIIRS

• Ingest into NCEP models where near real-time GVF leads to better partition between surface heating & evaporation --> impacts surface energy budget, PBL evolution, clouds & convection.

• Initial summertime GFS tests in 2013, 2014, 2015 show improvements in low-level temperature and dew point, land-surface temperature.

• Part of a broader effort for land product data set ingest with focus on internal consistency among various products (i.e. albedo, burned area, soil moisture, etc).

Weizhong Zheng, Yihua Wu (NCEP/EMC), Bob Yu, Ivan Csiszar, Marco Vargas et al (NESDIS/STAR)
NGGPS Project: Satellite-based Land Data Assimilation in NCEP Modeling Systems

- Use NASA Land Information System (LIS) to serve as a global Land Data Assimilation System (LDAS) for testing both GLDAS, NLDAS.
- LIS EnKF-based Land Data Assimilation tool used to assimilate:
  - Soil moisture from the NESDIS global Soil Moisture Operational Product System (SMOPS).
  - Snow cover area (SCA) from operational NESDIS Interactive Multisensor Snow and Ice Mapping System (IMS), and AFWA snow depth (SNODEP) products.

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NGGPS Project: Land Data Assimilation

Michael Ek, Jiarui Dong, Weizhong Zheng (NCEP/EMC)
Christa Peters-Lidard, Grey Nearing (NASA/GSFC)

1. Build NCEP’s GFS/CFS-LDAS by incorporating the NASA Land Information System (LIS) into NCEP’s GFS/CFS (left figure)
2. Offline tests of the existing EnKF-based land data assimilation capabilities in LIS driven by the operational GFS/CFS.
3. Coupled land data assimilation tests and evaluation against the operational system.

Jiarui Dong, NCEP/EMC
NGGPS: Demonstration of land data assimilation of AFWA Snow Depth (initially under LIS)

Open Loop

12/31/2014 00Z

Direct Insertion

07/01/2014 00Z

Control Run

GFS/GDAS (0.5x-2.0x)

Working on using LIS EnKF to assimilate AFWA snow depth. The successful EnKF applications require accurate error estimates both from satellite observations and from the land model.

Jiarui Dong, NCEP/EMC
Demonstration of land data assimilation of SMOPS Soil Moisture

- Noah land model multiple-year grid-wise means & std devs used to scale surface layer soil moisture retrievals before assimilation.
- Testing assimilation of SMOPS in GFS; positive impact on precipitation.

Weizhong Zheng, NCEP/EMC and Xiwu Zhan, NESDIS/STAR
Recent research has shown the unique value of satellite-based SM and snow retrievals and the feasibility of assimilating these retrieval products into the land surface models (LSMs) to improve the land-atmosphere water and energy exchange simulations.

The assimilation approach will run a series of assimilation experiments with the semi-coupled LIS/GFS system over a three-month warm-season period: (1) an open-loop simulation [no DA] and (2) simulations that assimilates all available MW observations and IMS/AFWA snow cover/depth products.

Each simulation will use a MODIS/VIIRS near-real-time GVF product, replacing the climatological fields currently used in the GFS.
• Noah surface model runs in semi-coupled mode with Climate Data Assimilation System version (CDASv2); daily update provides initial land states to operational Climate Forecast System version 2 (CFSv2).
• Forcing: CDASv2 atmospheric output, & “blended” precipitation, snow.
• Blended Precipitation: CPC satellite (heaviest weight in tropics); CPC gauge (heaviest mid-latitudes); model CDASv2 (high latitude).
• Snow: IMS cover & AFWA depth, cycled if within 0.5-2.0x “envelope”.
• 30+ year global land-surface climatology.
• Research/partners supported by NOAA Climate Program Office.
• **Motivation:** NCEP CFS Reanalysis ran 6 simultaneous “streams”; soil moisture time series may have trends and discontinuity due to insufficient land surface spin up (~1 year, where ~10-years+ required).

• **Solution:** Retrospective single-stream GLDAS2 with 10-year spin-up procedure to resolve the issues of spin-up and stream discontinuity.

• Significantly *improved soil moisture time series* in the *semi-arid regions* and *cold regions* where longer spin-up period required.

• **Reasonable** soil moisture *climatology*, and energy & water budgets.

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**Global Land Data Assimilation System (GLDAS) version 2**

**July 2012 Soil Moisture Anomaly from NCEP GLDASv2**

Jesse Meng, NCEP/EMC
LDAS Upgrade: Implementation of GLDAS in GFS

- CDASv2/GLDAS paradigm: adapt for Global Forecast System:
  - Noah land model physics upgrades; accommodate higher-res. GFS.
  - Land surface forcing/downscaling, e.g. precipitation.
  - Land data sets, e.g. land-use, soils, green vegetation fraction (GVF).
  - Land data assimilation, e.g. snow, soil moisture.
  - Replace soil moist. nudging which uses CDASv2/GLDAS climatology.
  - Hydrology/river routing for ocean coupling. *(National Water Center)*
  - Eventually one global high-resolution LDAS for all NCEP systems.

- Continue to work with partners: Noah LSM model development group; NWS NGGPS land/other teams; NOAA CPO MAPP Task forces on reanalyses, model development, drought.

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**NCEP Realtime Operational GLDAS**

Vegetation Type Data

Soil Type Data

Jesse Meng and Helin Wei, NCEP/EMC
Precipitation Data:
- Gauge-satellite blended analysis of daily global precipitation.
- 0.25° lat/lon over the global land.
- Global daily analysis, 0.25-deg, 1979-present.
- Blending information from different sources:
  - CPC daily gauge analysis.
  - GPCC monthly gauge data.
  - OLR-based precipitation estimates.
  - CMORPH-based precipitation estimates.

Preliminary Results:
- Improved soil moisture spin-up & anomalies.

Courtesy of Pingping Xie, NCEP/CPC
North American Land Data Assimilation System (NLDAS) Operational at NCEP 05 August 2014

- Land models: Noah, SAC, VIC, Mosaic run in “uncoupled” mode.
- Forcing: NCEP Climate Prediction Center obs precip (gauge-based, radar/satellite disaggregated), and atmospheric forcing from NCEP North American Regional Climate Data Assimilation System.
- Climatology from land model assimilation runs for 30+ years provide **anomalies** used for **drought monitoring**; supports USDM, NIDIS etc.
- Comprehensive evaluation of **energy fluxes**, **water budget** and **state variables** using in situ and remotely-sensed data sets.

(ldas.gsfc.nasa.gov/nldas/NLDAS2valid.php)

www.emc.ncep.noaa.gov/mmb/nldas

NLDAS four-model ensemble monthly soil moisture anomaly  Youlong Xia, NCEP/EMC

- July 30-yr climate
- July 1988 (drought)
- July 1993 (flood)
- July 2011 (TX drought)
**LDAS Upgrade: NLDAS Future**

- **Bring NLDAS up to real-time**: Close 3.5-day lag in current operational NLDAS, using NARR, NDAS, & NAM analysis & forecast data, replace NDAS/NAM downward shortwave radiation with GOES retrievals to overcome shortcomings, and for precipitation: 0.125-deg CPC operational global gauge-based daily global analysis & NAM 48-hour forecast precipitation.

- Forcing at \( \sim 3-4\text{km resolution} \); downscaling issues.
- **LSM physics upgrades** for Noah, SAC, Catchment (move from Mosaic), VIC; add additional LSMs.
- **New high-res land-use (veg.) & soils data sets.**
- **LIS-based land data assimil.** Snow/soil moisture.
- **Extend domain to North America** to provide initial land states to NAM & support N. A. Drought Monitor.
- Continue to work with our key NLDAS partners, including NASA & National Water Center, academic community on forcing data set generation (e.g. Precip) & Noah LSM/hydrology model development.
- **NOAA Climate Program Office Drought Task Force.**

Youlong Xia, NCEP/EMC
LDAS Upgrade: Finer-Resolution Forcing Input for NLDAS

Re-run of URMA retrospective analysis producing 2.5-km 30 years historical mesoscale reanalysis for CONUS and Alaska.

Comparison of UnRestricted Mesoscale Analysis (URMA) and NLDAS forcing

Downscaling and merging of precipitation (CPC OLR-based latest product)

Snapshots of precipitation events in 2013. Stage IV and NLDAS precipitation are compared against OLR precipitation.

Roshan Shretha, NCEP/EMC
**Model Physics Improvement: Noah-MP**

Noah-MP is an extended version of the Noah LSM with enhanced multi-physics options to address shortcomings in Noah.

- Canopy radiative transfer with shading geometry.
- Separate vegetation canopy.
- Dynamic vegetation.
- Ball-Berry canopy resistance.
- Multi-layer snowpack.
- Snow albedo treatment.
- New snow cover algorithm.
- Snowpack liquid water retention.
- New frozen soil scheme.
- Interaction with groundwater/aquifer.

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Noah-MP references: Niu et al., 2011, Yang et al., 2011. *JGR*
Model Improvement: Freshwater Lakes

- **Thousands** of lakes on scale of 1-4km not resolved by SST analysis -> greatly influence surface fluxes; explicit vs subgrid.
- Freshwater lake “**FLake**” model (*Dmitrii Mironov, DWD*).
  - Two-layer.
  - Atmospheric forcing inputs.
  - Temperature & energy budget.
  - Mixed-layer and thermocline.
  - Snow-ice module
  - Specified depth/turbidity.
  - Used in COSMO, HIRLAM, NAM (regional), and global ECMWF, CMC, UKMO.

Yihua Wu, NCEP/EMC
Model Improvement: Hydrology, River-Routing

Atmospheric Forcing

Surface flow

Saturated subsurface flow

Groundwater

Ensemble mean daily streamflow anomaly (NLDAS)

- Hurricane Irene and Tropical Storm Lee, 20 August – 17 September 2011
- Superstorm Sandy, 29 October – 04 November 2012
- Colorado Front Range Flooding, September 2013

Close Coordination with National Water Center
Testing & Validation: Simple-to-More Complex Hierarchy of Model Parameterization Development

- Simulators: test submodel parameterizations at process level, e.g. radiation-only, land-only, etc.
- Testbed data sets to develop, drive & validate submodels: observations, models, idealized, with “benchmarks” before adopting changes.
- Submodel interactions, with benchmarks.
- Full columns, with benchmarks.
- Limited-area/3-D (convection) with benchmarks.
- Regional & global NWP & seasonal climate, with benchmarks.
- More efficient model development, community engagement, R2O/O2R & computer usage.

Simulators
- Radiation
- Clouds & convection
- Microphysics
- Boundary-Layer
- Surface-layer
- Land
- Sea-ice
- Ocean, Waves

Interaction tests

Column tests

Limited-area

Regional & Global

- Close Interaction with NOAA Testbeds
Testing and Validation: Surface-layer Simulator

• GOAL: Improve surface turbulence exchange coefficients.
• Surface-layer simulation ("SLS") code simulates surface-layer and schemes from meso-NAM and medium-range GFS.
• Use observations to drive SLS (U,T,q and Tsfc) and compare with inferred Ch, Cd from independent “fluxnet” obs (H, LE, $\tau$).
• Bias in surface exchange coefficient for heat dependent on vegetation height. Action: adjust thermal roughness parameter.

Caterina Tassone, NCEP/EMC
Testing and Validation: Land Model & Sfc-Layer

- **Validation** uses near-surface observations, e.g. routine weather observations of air temperature, dew point and relative humidity, 10-meter wind, along with upper-air validation, precipitation scores, etc.

- To more fully validate land models at the **process level**, surface **fluxes** and soil states (soil moisture, etc) are also used.

- Monthly diurnal composites to **assess systematic model biases** (averaging out transient atmospheric conditions), and suggest land physics upgrades.
Testing & Validation: Land Model Benchmarking

- **Benchmarking**: Decide how good model needs to be, then run model and ask: *Does model reach the level required?*
- **Protocol for the Analysis of Land Surface models (PALS)**: [www.pals.unsw.edu.au](http://www.pals.unsw.edu.au). GEWEX/GLASS project.
- Compare models with empirical/statistical approaches, previous model versions, other land models. Different plots/tables of model validation and benchmarking metrics.
- Identify systematic biases for model development/validation.

PALS example: CABLE (BOM/Aust.) land model, Bondville, IL, USA (cropland), 1997-2006, avg diurnal cycles.

Martin Best (UKMO), Gab Abramowitz (UNSW) et al.
Testing & Validation: (uncoupled) NLDAS

Comprehensive evaluation against in situ observations and/or remotely sensed data sets.

Energy flux validation from tower: net radiation, sensible, latent & ground heat fluxes.

Water budget: evaporation, total runoff/streamflow.

State variables: soil moist., soil/skin temp., snow depth/cover.

Monthly streamflow anomaly correlation (1979-2007 USGS measured streamflow)

Xia et al., JGR-atmosphere (2012)

Daily top 1m soil moisture anomaly corr. (2002-2009 US SCAN Network)

Sub-Regions RMSE<0.06 m$^3$/m$^3$

Xia et al., J. Hydrol. (2014)
Testing & Validation: Column Model Testing

Diurnal land-atmosphere coupling experiment (DICE)

**Objective:** Assess impact of land-atmosphere feedbacks.
Stage 1: stand alone land, and single column model (SCM) alone.
Stage 2: Coupled land-SCM.
Stage 3: Sensitivity of LSMs & SCMs to variations in forcing.

**Data Set:** CASES-99 field experiment in Kansas, using 3 days: 23-26 Oct 1999, 19UTC-19UTC.

**Joint GEWEX GLASS-GASS project** – outgrowth of GABLS2 (boundary-layer project) where land-atmosphere coupling was identified as an important mechanism. ~10 models participating.
Testing and Validation: Fully Coupled GFS

- Forecast only
- Cycled
- Full parallel
- Metrics: precip, 500mb AC, upper air, surface temp/wind, etc
- Examples

Results from the new LSC dataset tests on the GFS

Helin Wei, NCEP/EMC
Land Prediction at NCEP: Summary/Future

• Improve & unify Noah land model and GLDAS/NLDAS at NCEP:
  – Forcing, e.g. precipitation, & land data sets, e.g. near-realtime GVF.
  – Run GLDAS, NLDAS under NASA Land Information System (LIS):
    parallel run environment, latest land model versions, land data sets, data assimilation/validation tools for e.g. snow, soil moisture.
  – Land model physics improvements, including next-generation “Noah-MP” with dynamic vegetation, etc; account for agriculture, irrigation, etc; lakes; hydrology/groundwater/river-routing.
  – Higher resolution and downscaled forcing and model output.
  – Enhance land model spin-up procedures.
  – Extend domain/resolution of NLDAS to North America, to then “merge” with GLDAS for global models (GFS, CFS), providing unified initial land conditions for all NCEP regional, global and climate models.
  – Comprehensive hierarchy of model development and evaluation.

• Land models role expanding for weather & climate in increasingly more fully-coupled Earth-System Models (atmosphere-ocean-land-ice-waves-aerosols) with connections between Weather & Climate and Hydrology, Ecosystems & Biogeochemical cycles (e.g. carbon), and Air Quality, models and communities, i.e. under community model development, e.g. NOAA Environ. Modeling System (NEMS).